ASU Sound & Vibration Lab

Faculty of Engineering
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Acoustics

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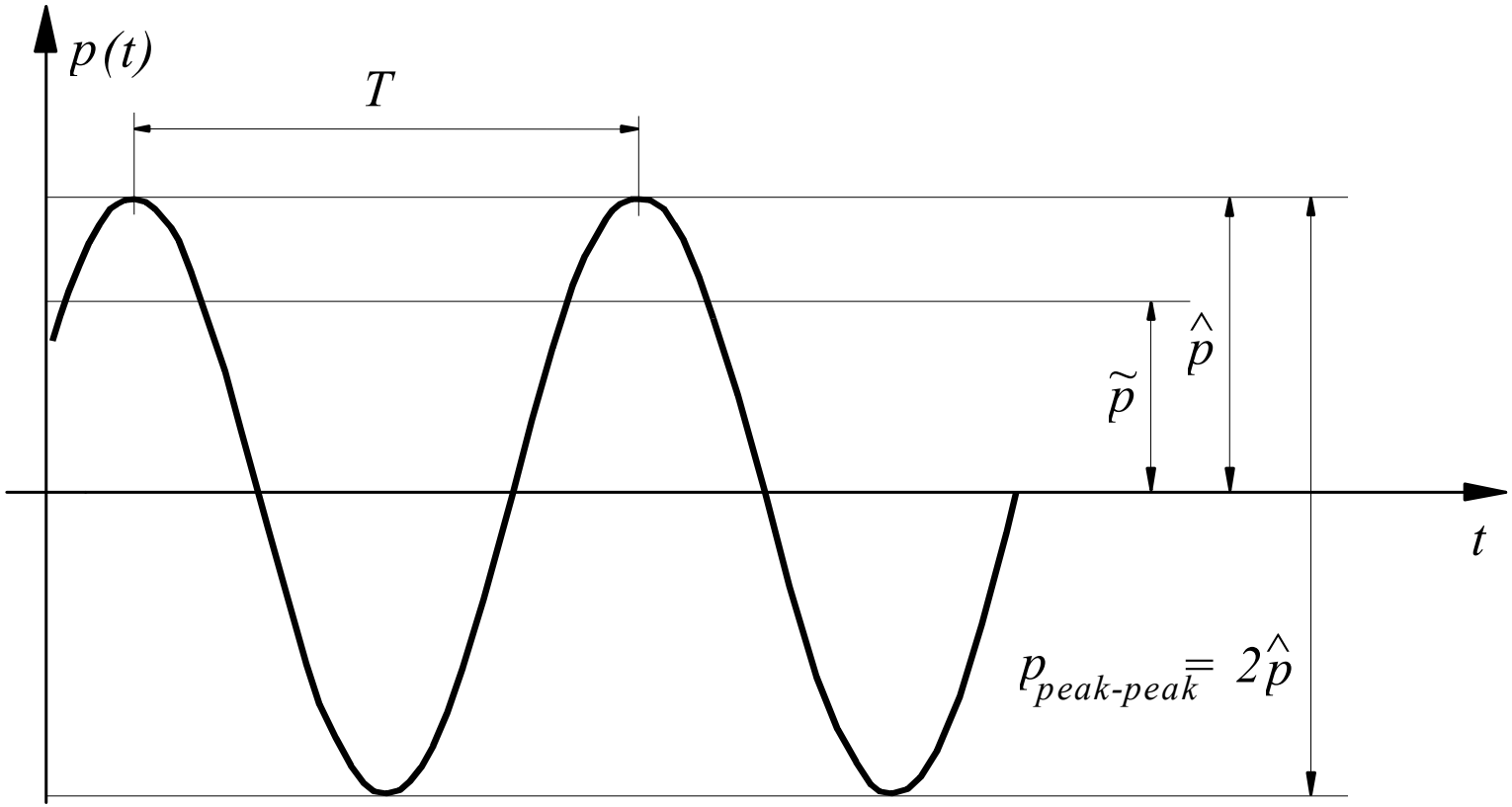
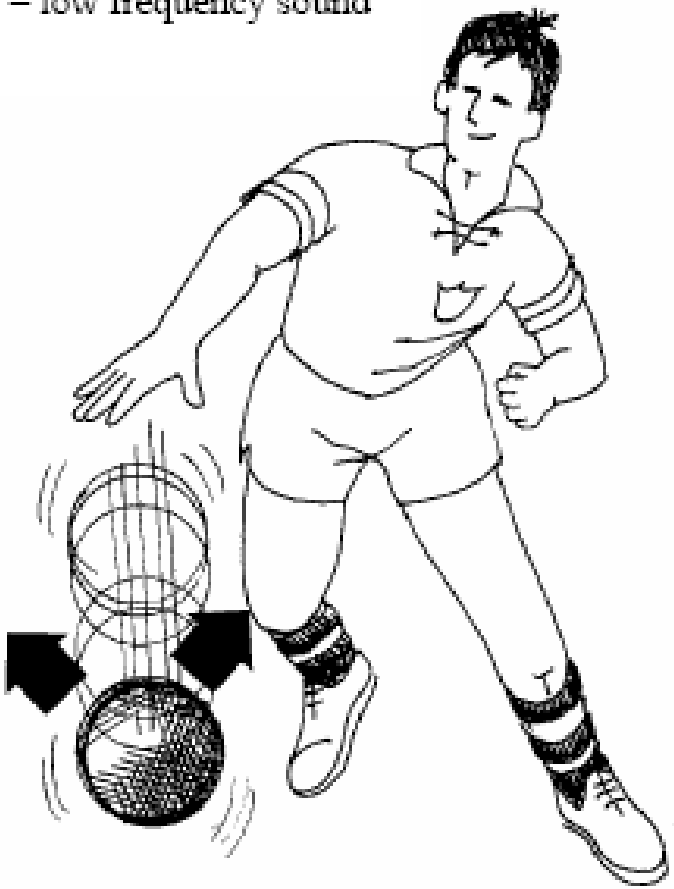
#2: Basic Concepts

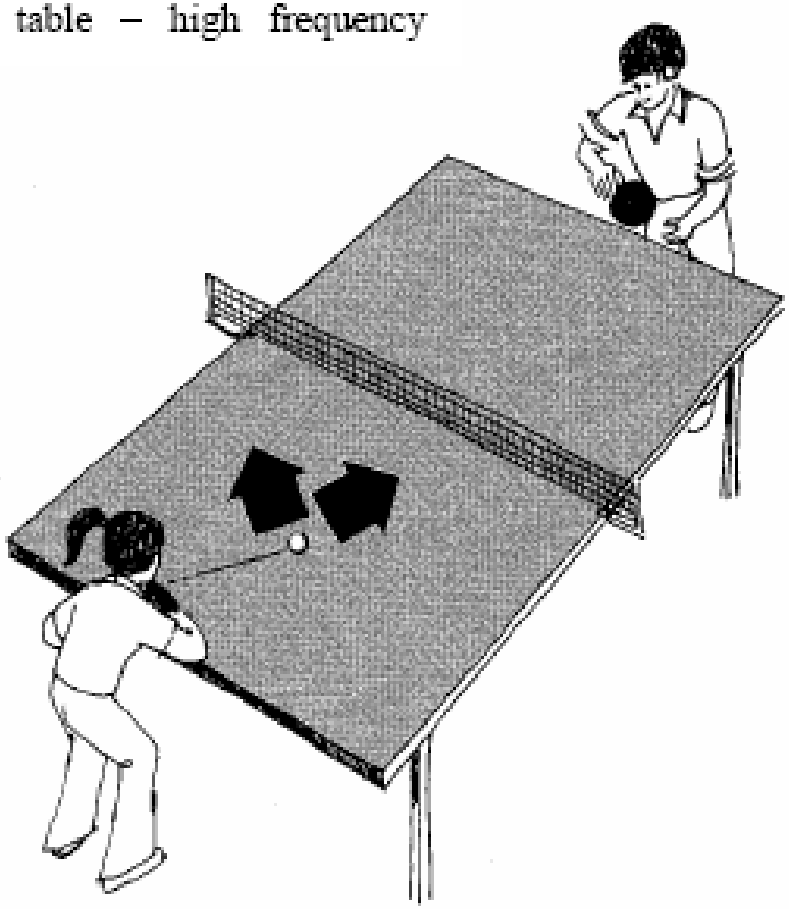
Amplitude and Frequency

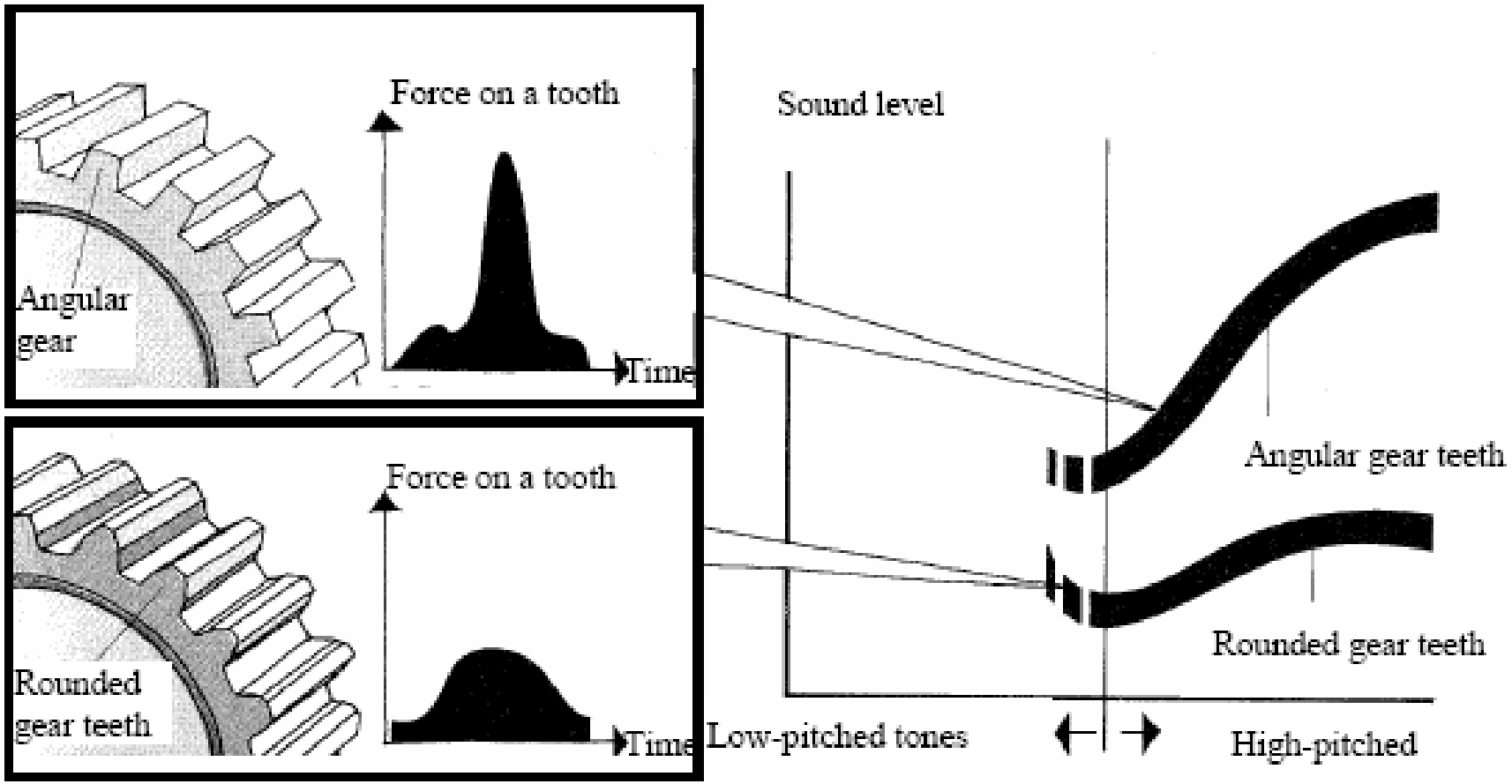


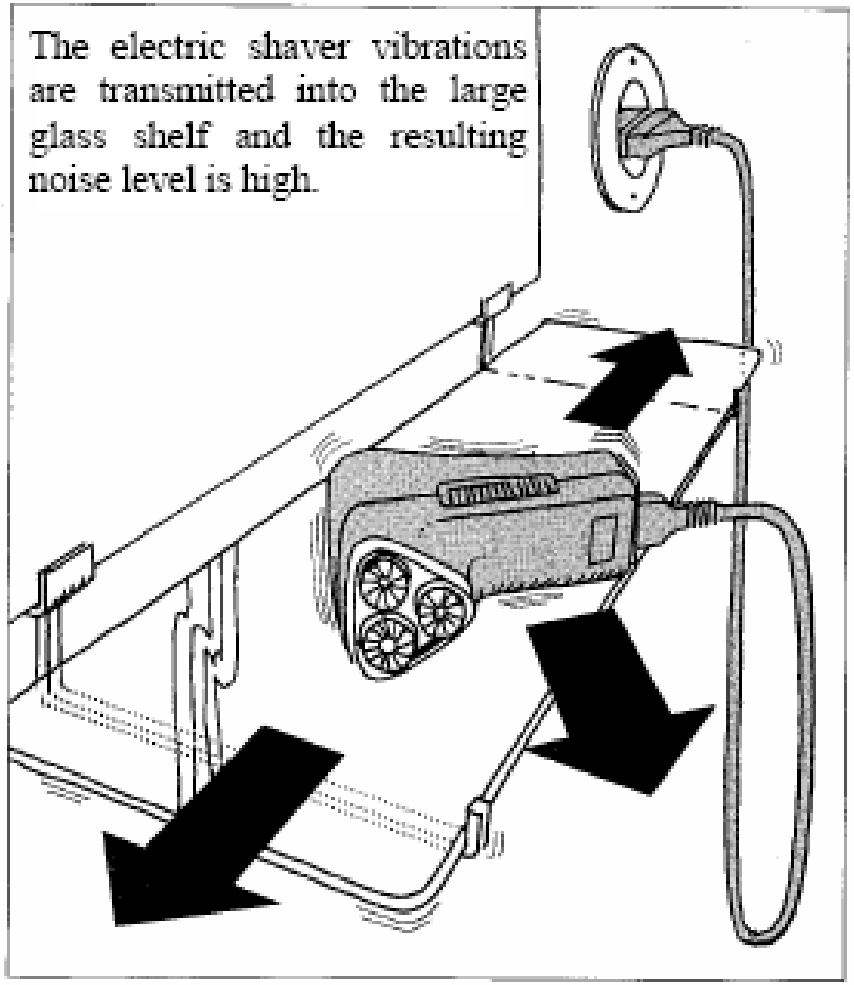
Slow impact against the floor – low frequency sound

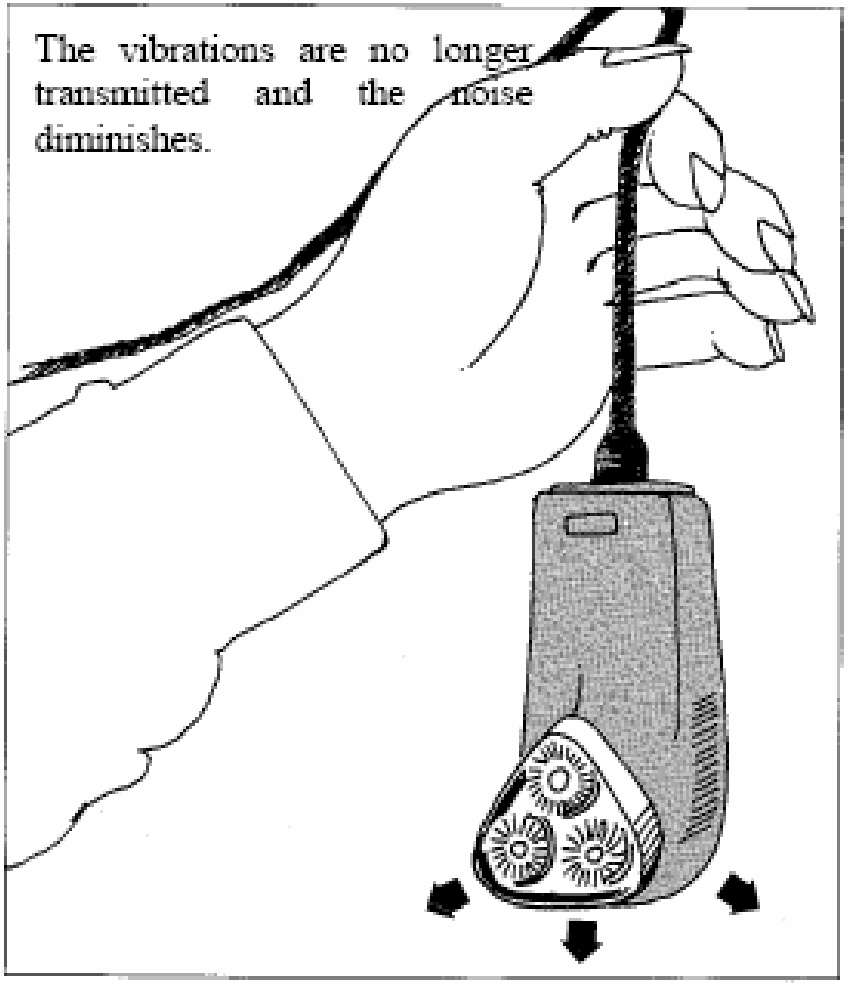


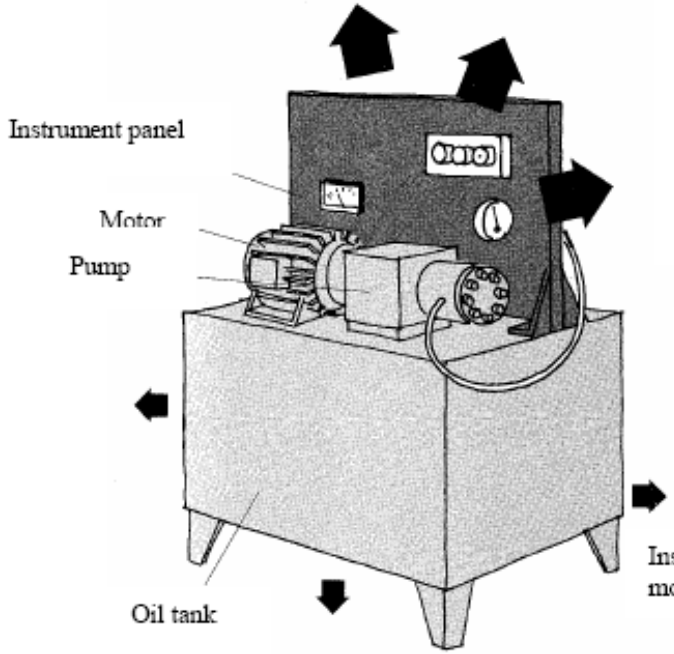
Rapid impact against the table – high frequency




Force on a tooth
Angular gear
Time
Force on a tooth
Rounded gear teeth
Time
Sound level
Angular gear teeth
Rounded gear teeth
Low-pitched tones
High-pitched


The electric shaver vibrations are transmitted into the large glass shelf and the resulting noise level is high.


The vibrations are no longer transmitted and the noise diminishes.

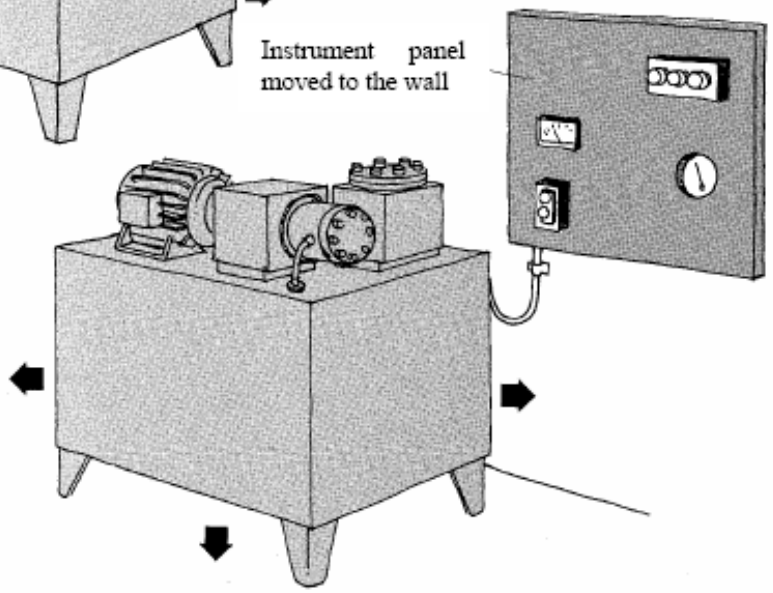


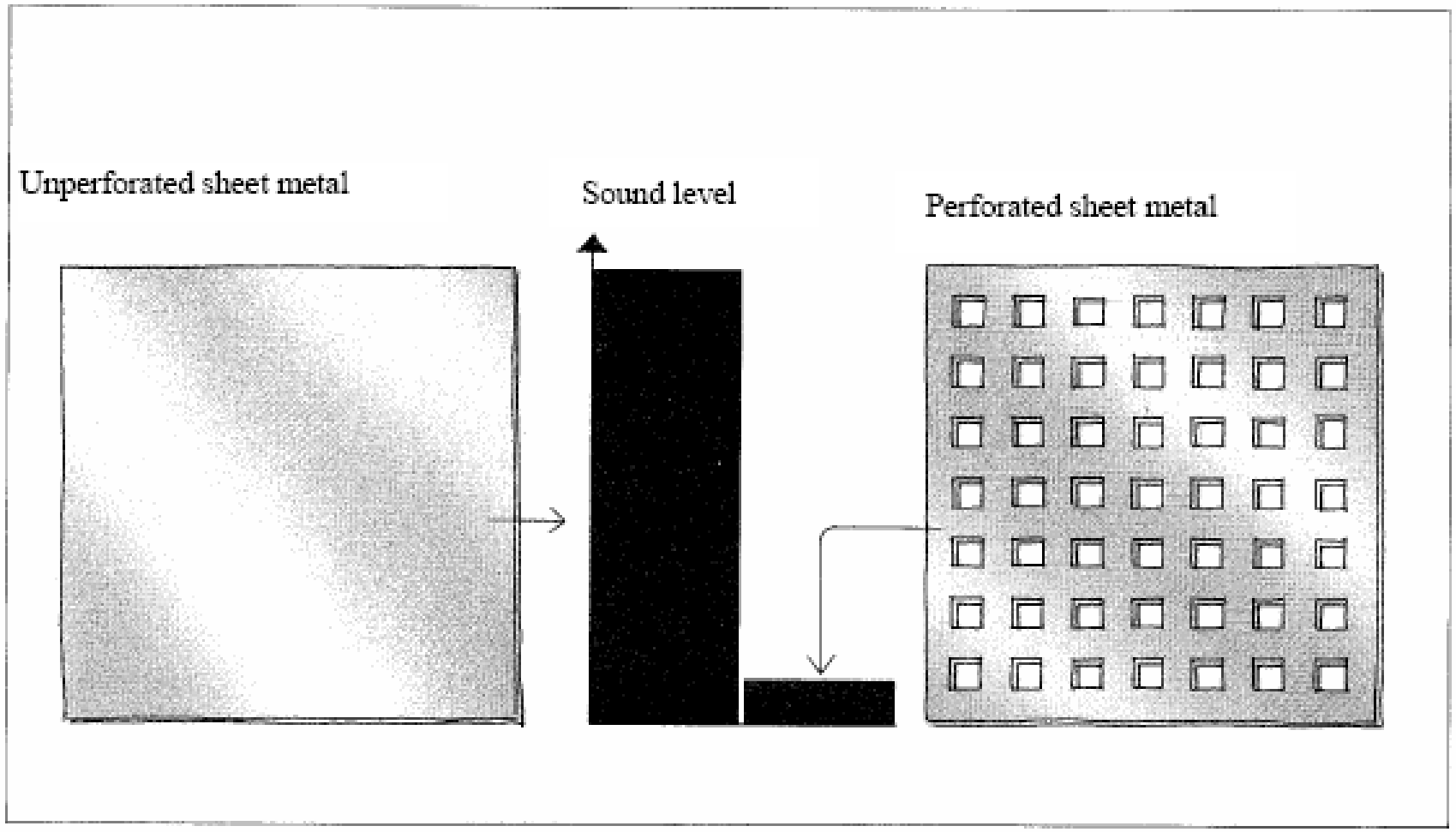
***Example*:**

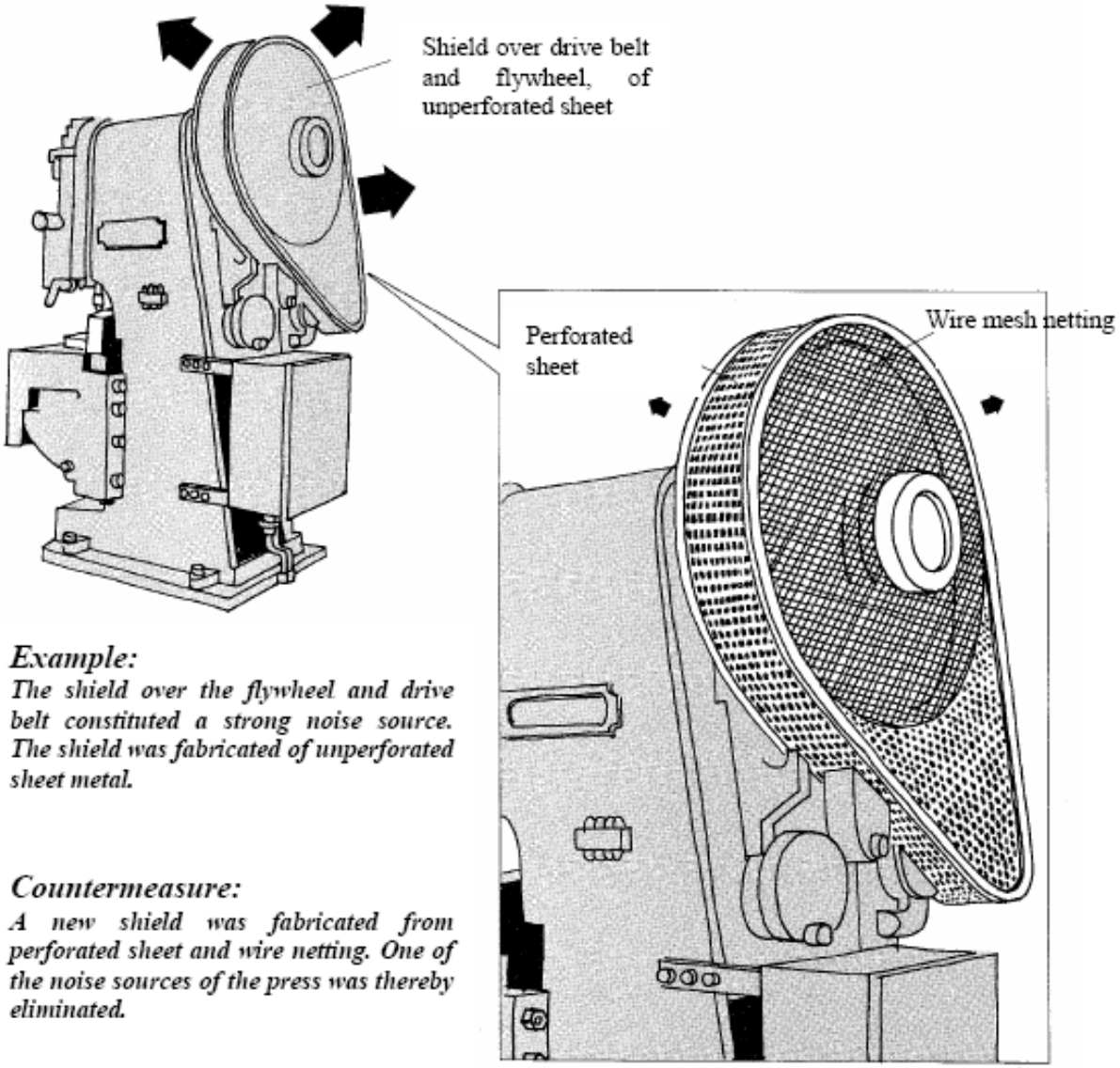
The hydraulic aggregate was a powerful noise source. Since the wall vibrations of the oil tank were damped by the oil itself, most of the noise was radiated by the instrument panel.

Countermeasure:

The panel was separated from the aggregate, reducing the radiating surface area, and thereby even the noise level.




Unperforated sheet metal
Sound level
Perforated sheet metal

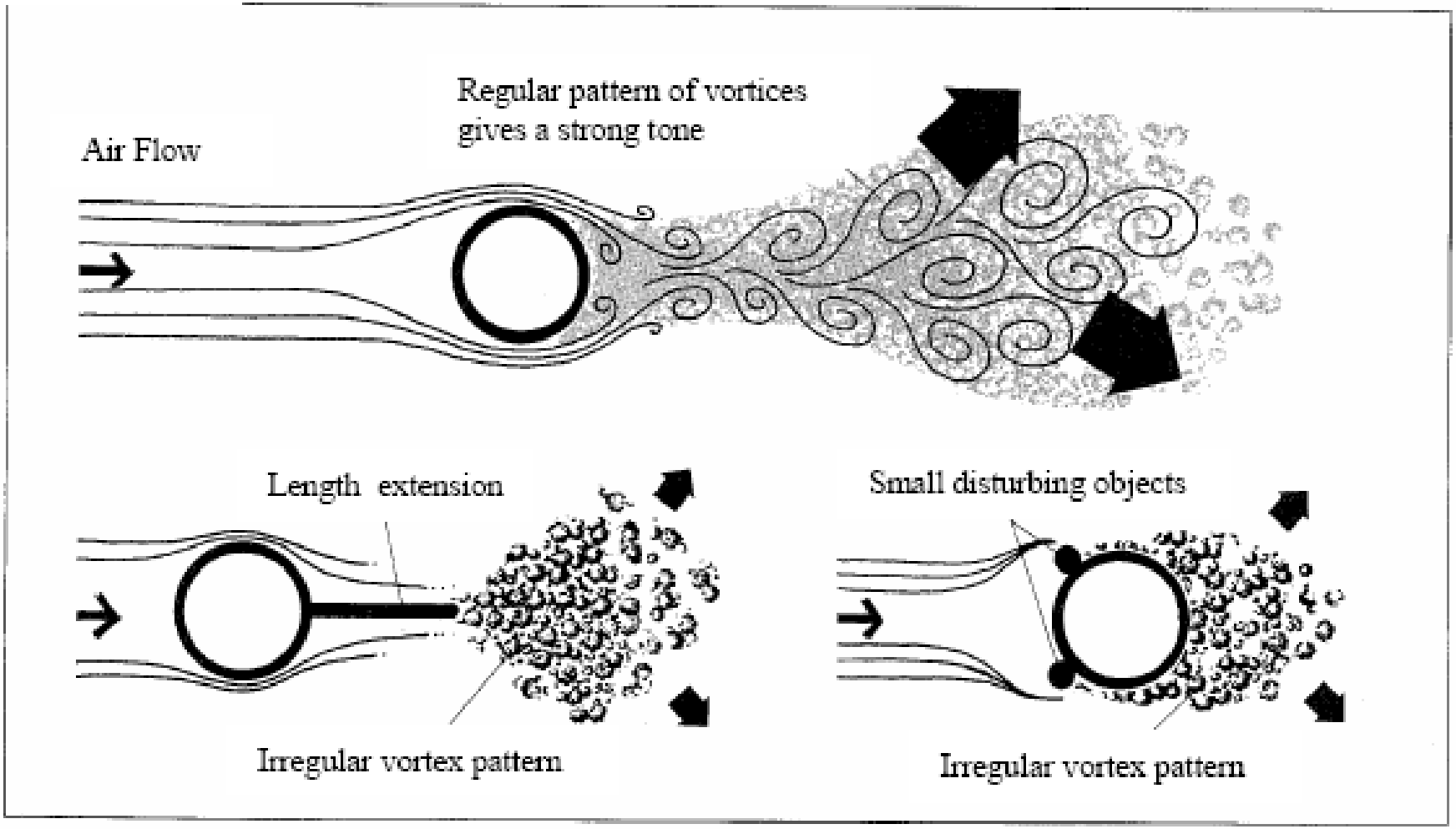


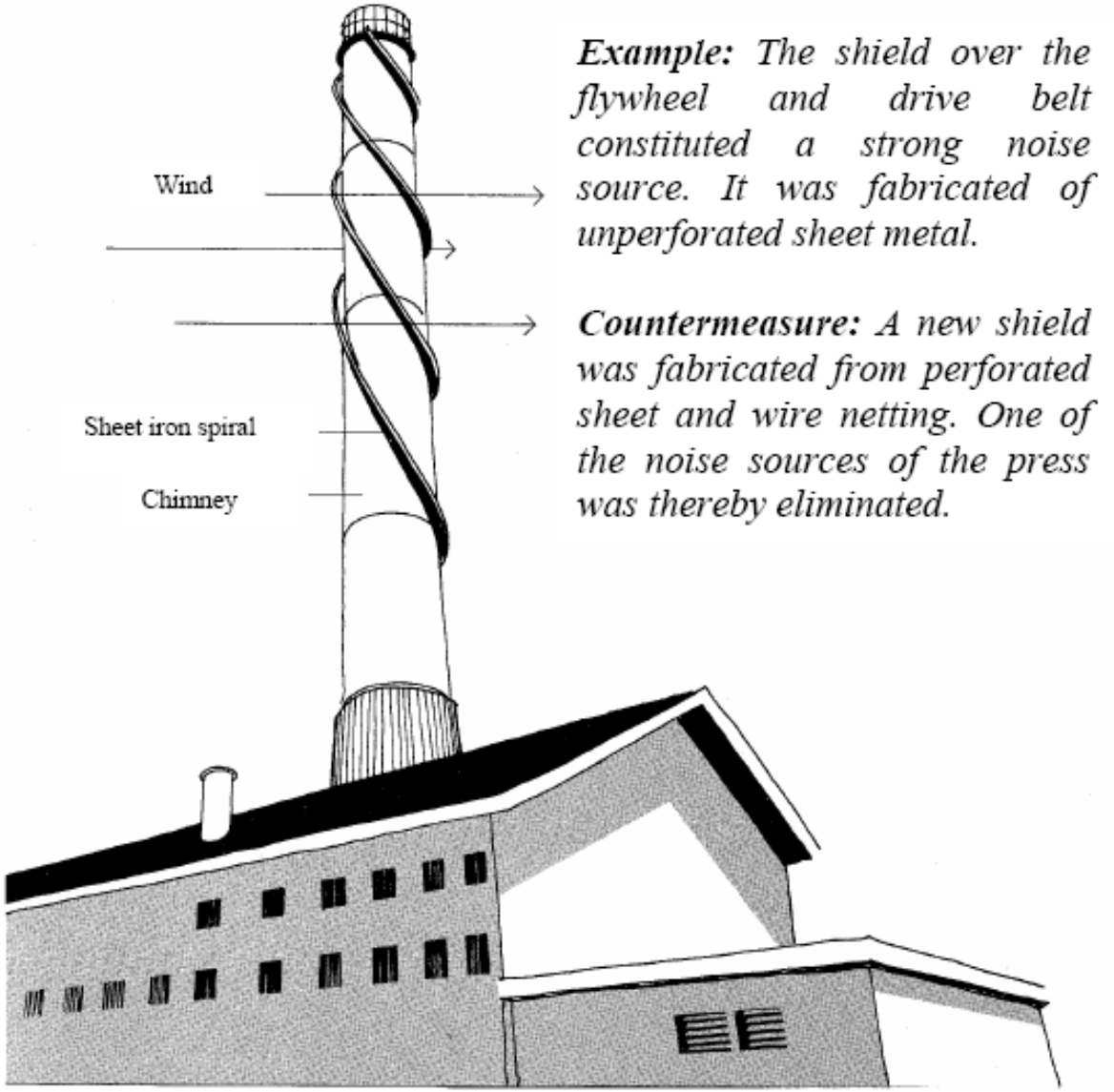
Example:

The shield over the flywheel and drive belt constituted a strong noise source. The shield was fabricated of unperforated sheet metal.

Countermeasure:

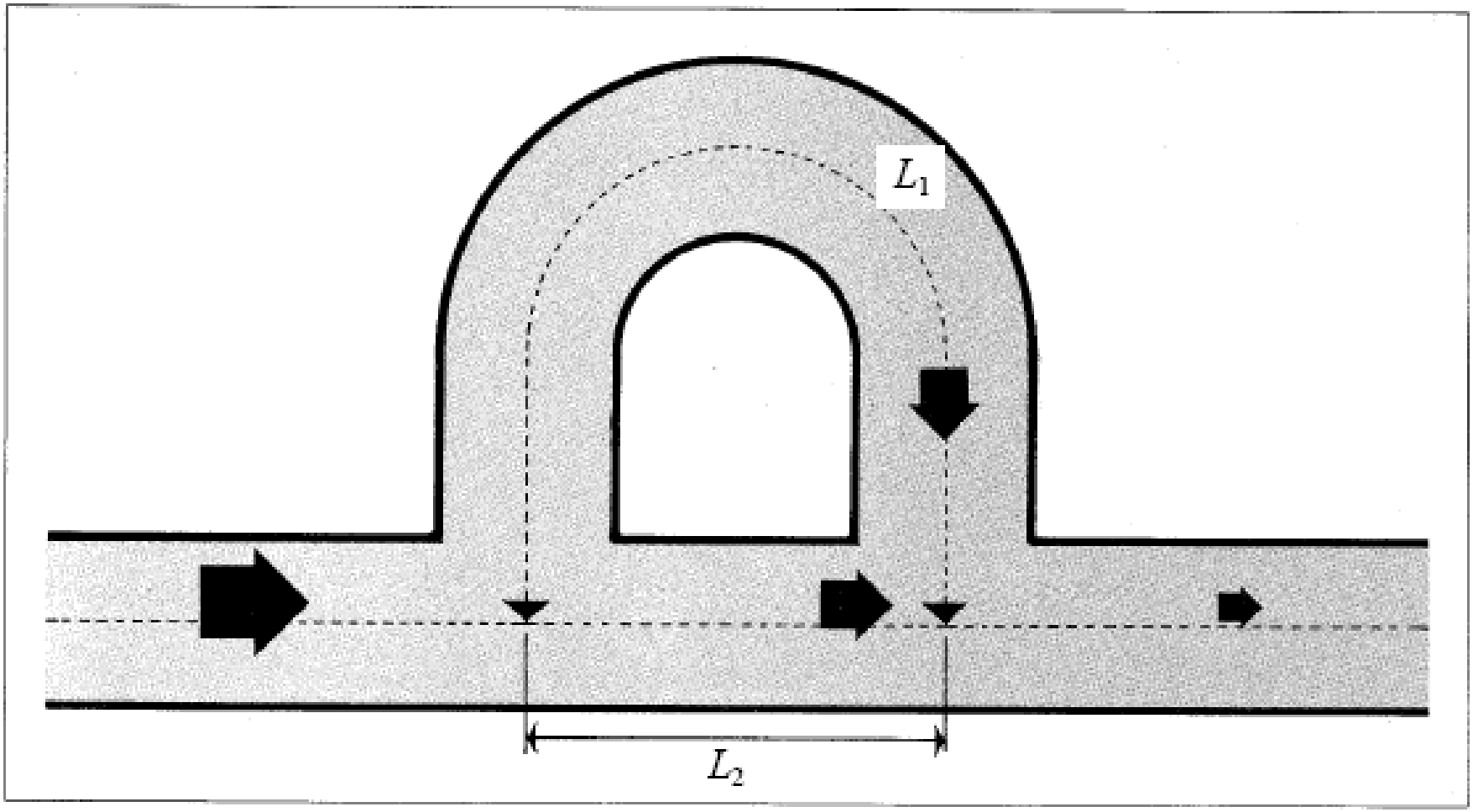
A new shield was fabricated from perforated sheet and wire netting. One of the noise sources of the press was thereby eliminated.

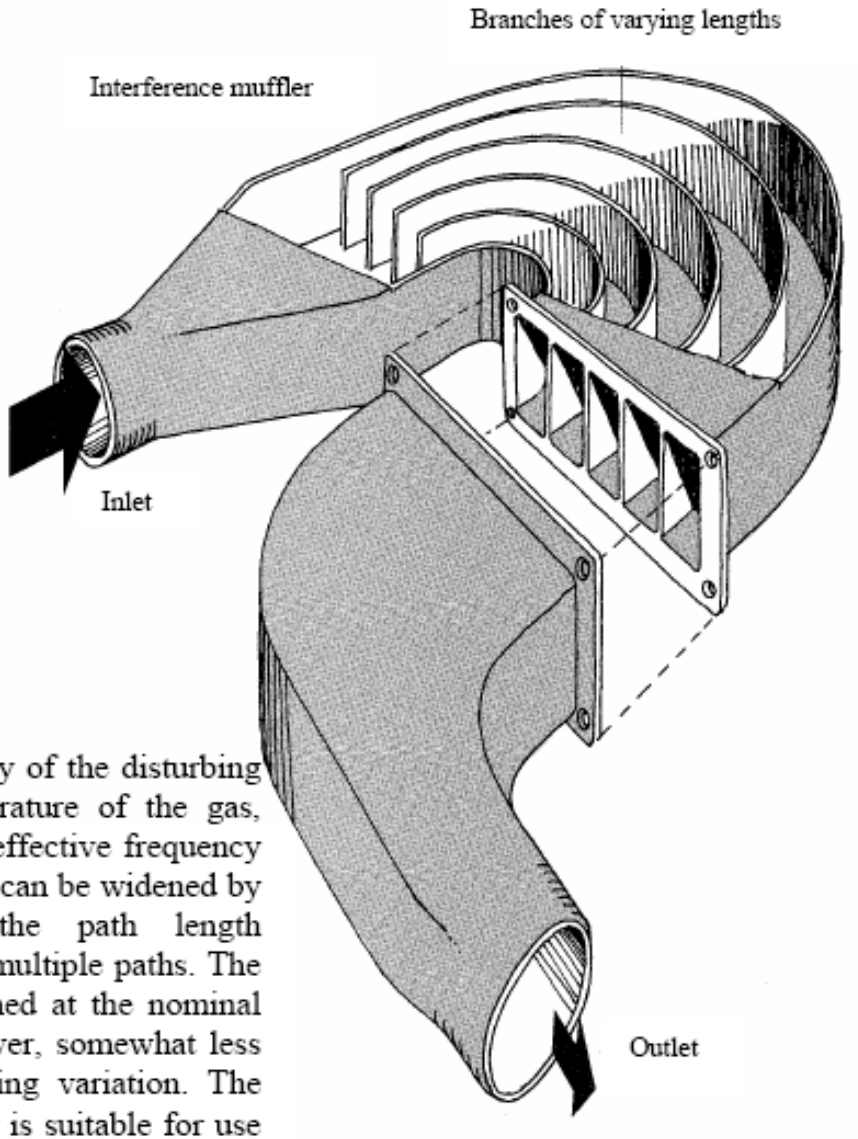

Regular pattern of vortices
gives a strong tone
Air Flow
Length extension
Small disturbing objects
Irregular vortex pattern
Irregular vortex pattern



Example: *The shield over the flywheel and drive belt constituted a strong noise source. It was fabricated of unperforated sheet metal.*

Countermeasure: *A new shield was fabricated from perforated sheet and wire netting. One of the noise sources of the press was thereby eliminated.*


L_1
L_2



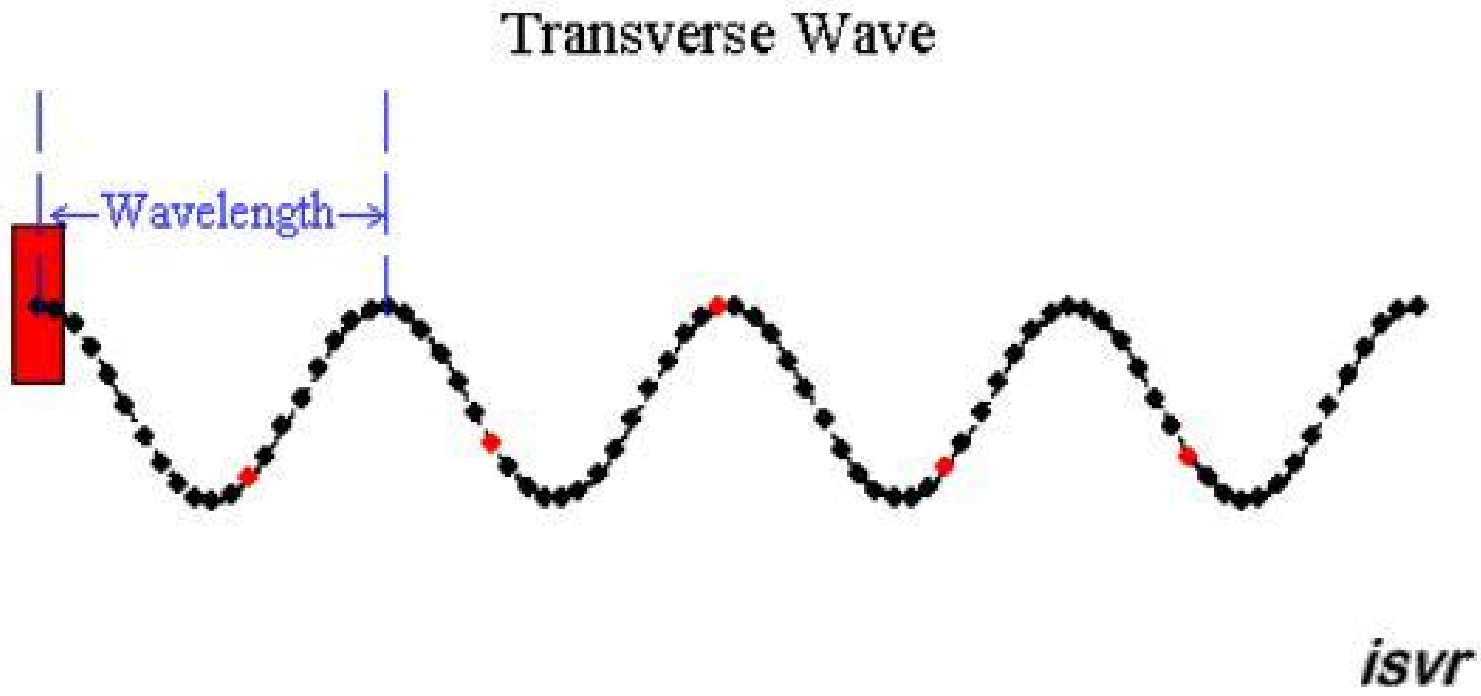
Example:

When the frequency of the disturbing tone, or the temperature of the gas, varies in time, the effective frequency band of the muffler can be widened by a variation of the path length difference through multiple paths. The improvement obtained at the nominal frequency is, however, somewhat less than in the preceding variation. The interference damper is suitable for use

Sound Waves

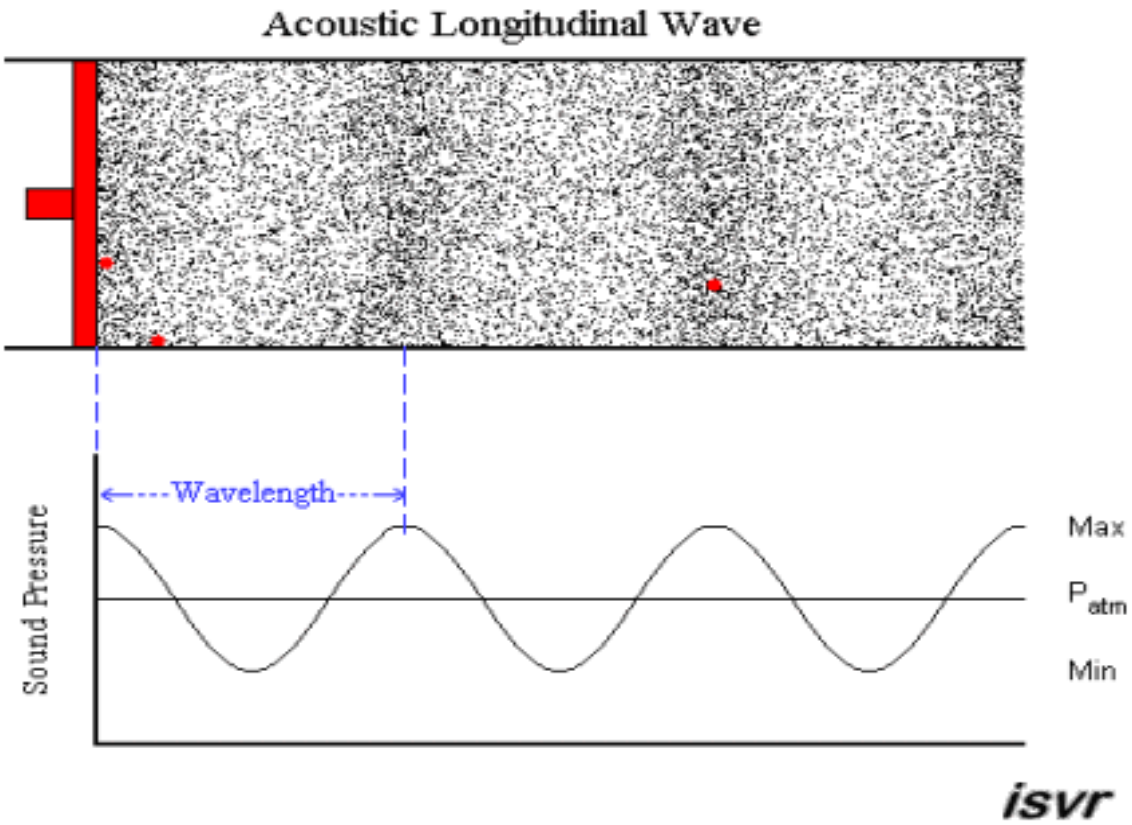
SOUND WAVES

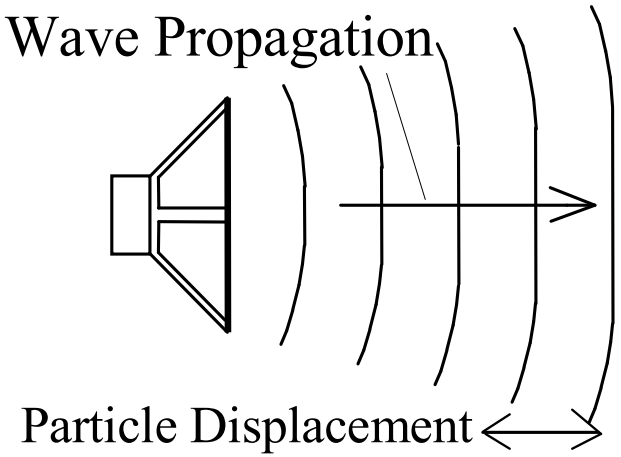
- Sound is a wave phenomenon.
- Waves in strings, beams, plates etc are *transverse* waves.
- Particle motion is transverse to direction of wave propagation.
- Waves transfer *energy* without transferring matter.

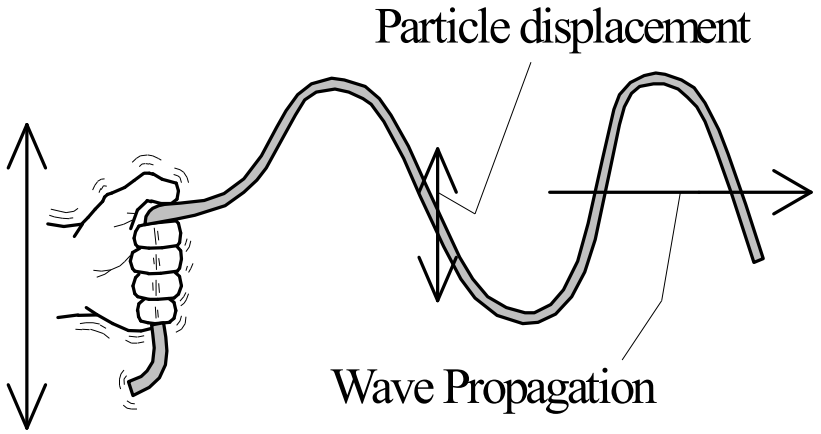


SOUND WAVES

- Sound waves are *longitudinal* waves.
- Fluid is compressed/expanded as ‘particles’ move.




Wave Propagation
Particle Displacement


Particle displacement
Wave Propagation

SOUND QUANTITIES

Sound involves a small time-varying disturbance of

- the **density** of a fluid from its equilibrium value,
- the **pressure** of a fluid from its equilibrium value,
- oscillatory movements (**vibration**) of the fluid 'particles'.

We usually measure **sound pressure**.

NB **Sound pressures** are typically less than 1 Pa (Nm^{-2}).
At 100 Pa they would be literally deafening.
Atmospheric pressure = 1.013×10^5 Pa (1 bar).

FREQUENCY AND WAVELENGTH

The **frequency**, f determines how rapidly the sound changes with *time*.

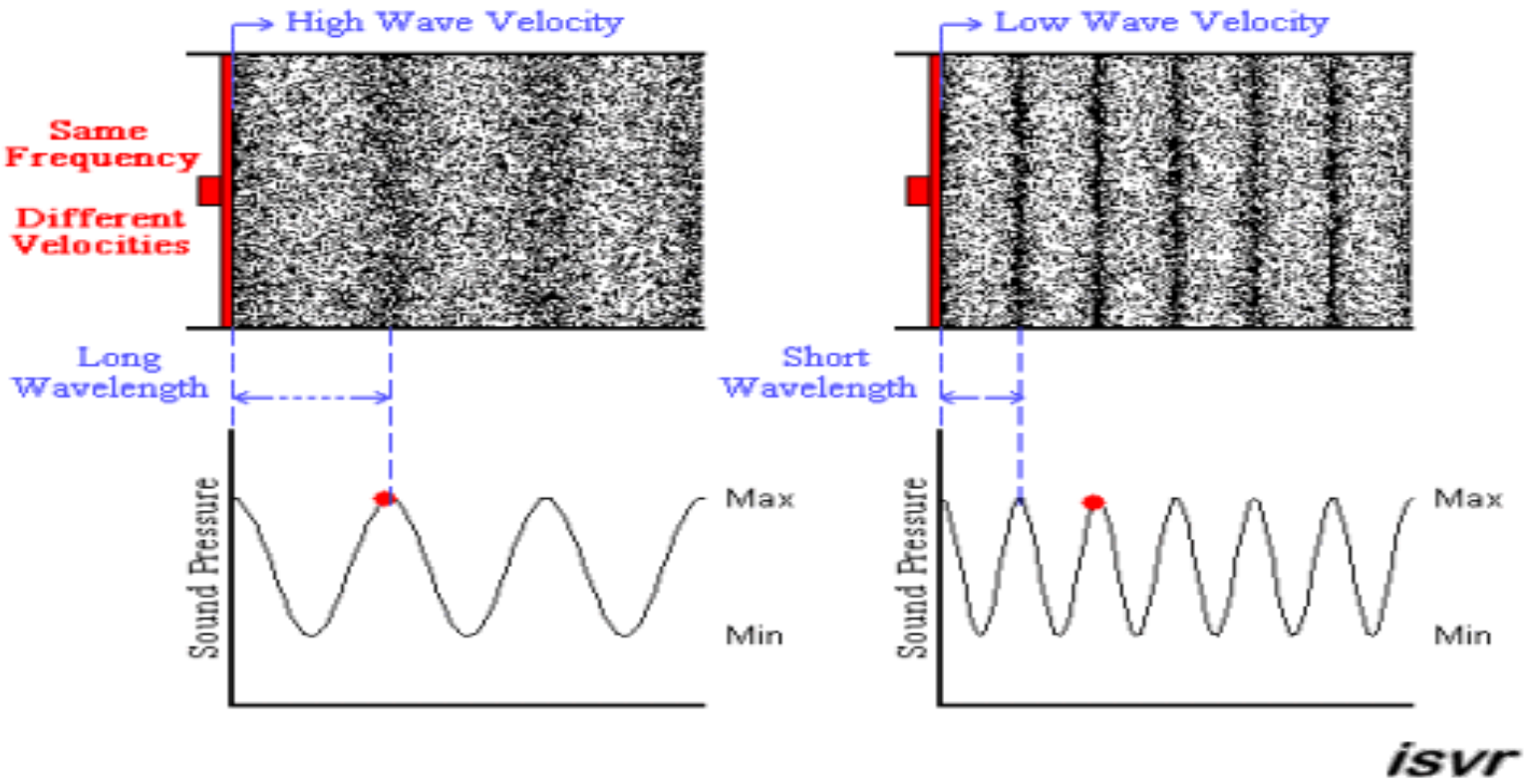
The *distance* between adjacent peaks is called the **wavelength**, λ.

Frequency and wavelength are related by the **wavespeed**, c.

$$c = f\lambda$$

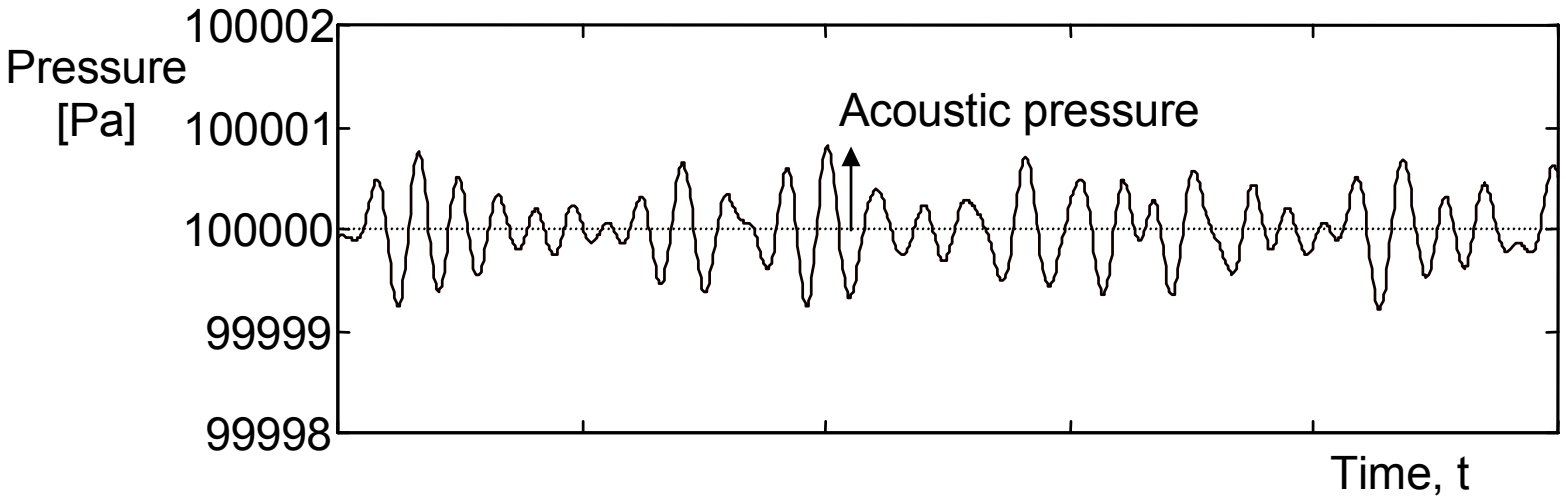
$$c = f\lambda$$

Two acoustic waves with different frequencies but the same wavespeed.
The wavelength is halved when the frequency is doubled.



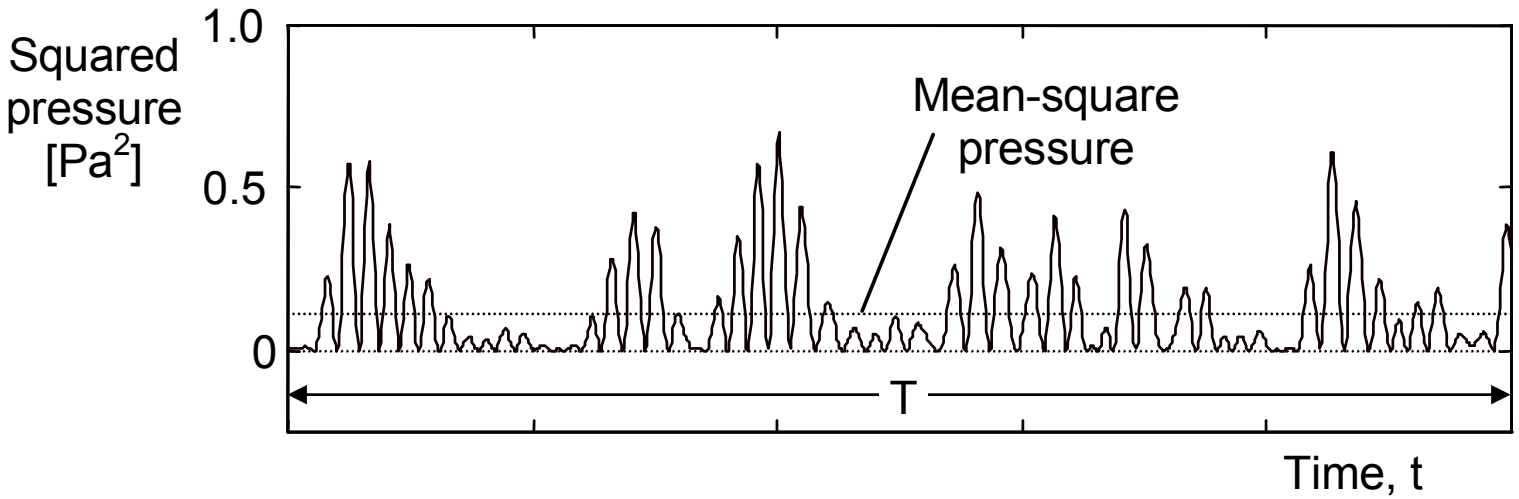
Measures of Sound

MEASURES OF SOUND



- Average pressure is equal to atmospheric pressure.
- Small fluctuations around this value are acoustic pressure.

MEASURES OF SOUND



- Average the *squared* acoustic pressure (**mean-square**):

$$\overline{p^2} = \frac{1}{T}\int_{t_1}^{t_1+T} p^2(t)\,dt$$

- Square root of this is the **root mean square** (rms) pressure.
- It can depend strongly on the averaging time.

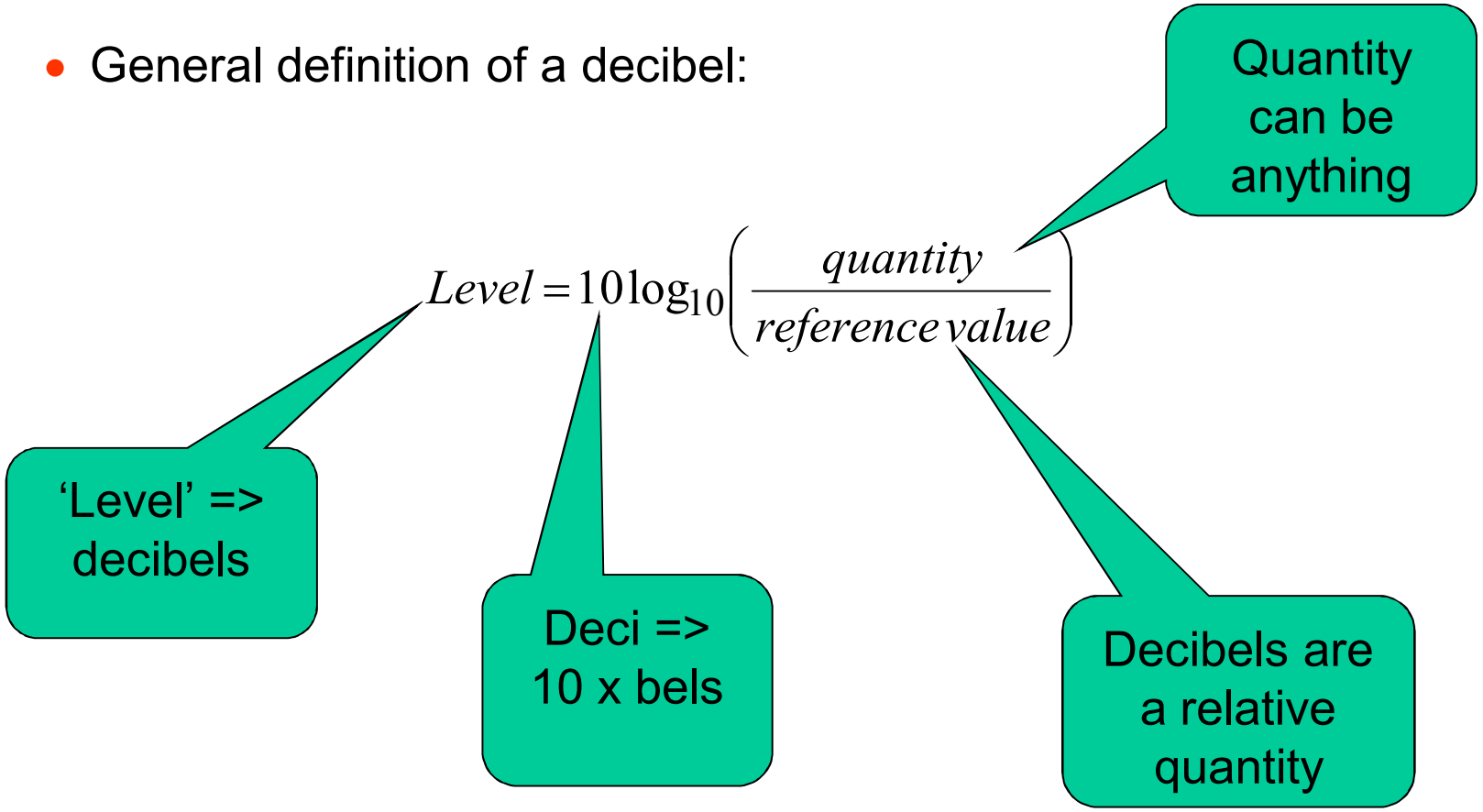
RANGE OF SOUND AMPLTIDES

- The human ear is sensitive to a very large range of pressure amplitudes:
  - threshold of hearing at 1000 Hz: 2×10^{-5} Pa
  - rustling leaves: 2×10^{-4} Pa
  - conversation: 0.01 Pa
  - noise inside a vehicle at idle: 0.1 Pa
  - noise inside a vehicle at 120 km/h: 1 Pa
  - threshold of feeling: 20 Pa
  - threshold of pain: 200 Pa

- The ear responds approximately logarithmically to sound. A doubling in pressure amplitude corresponds to a fixed change in 'loudness'. Therefore we usually use a logarithmic scale to define sound amplitudes.

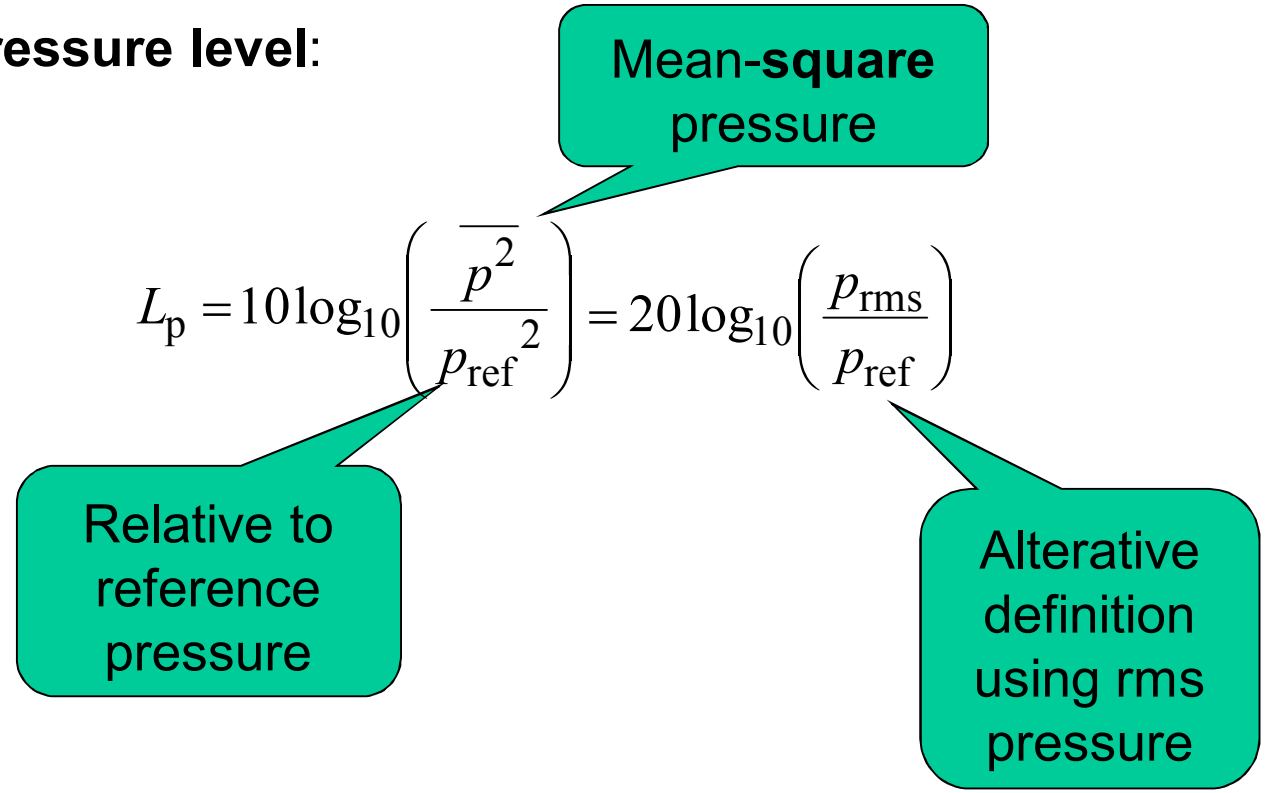
DECIBELS

- General definition of a decibel:



DECIBELS FOR SOUND PRESSURE

- **Sound pressure level**:



- p_{ref} is usually 2×10^{-5} Pa. Then we write: **dB re 2×10^{-5} Pa**.

Reference Pressure

- Here p_{ref} is a reference pressure which defines the amplitude of a pure tone at 1kHz which is just audible to the human ear.

  (*i.e.* the "threshold of hearing" corresponds to a sound pressure level of O dB.)

  For air $p_{\text{ref}} = 2 \times 10^{-5}$ Pa.

  (NOTE: the reference pressure for measurements in water is different. Need to take care to quote the reference pressure used!)

RANGE OF SOUND AMPLITUDES

- The large range of pressure amplitudes corresponds to a much smaller range of dB values:
  - threshold of hearing at 1000 Hz: 2×10^{-5} Pa – **0 dB**
  - rustling leaves: 2×10^{-4} Pa – **20 dB**
  - conversation: 0.01 Pa – **54 dB**
  - noise inside a vehicle at idle: 0.1 Pa – **74 dB**
  - noise inside a vehicle at 120 km/h: 1 Pa – **94 dB**
  - threshold of feeling: 20 Pa – **120 dB**
  - threshold of pain: 200 Pa – **140 dB**

PROPERTIES OF DECIBELS

- From the properties of logarithms:

Source & transfer function

$$\log(AB) = \log(A) + \log(B) \longrightarrow 10\log_{10}(AB) = 10\log_{10}(A) + 10\log_{10}(B)$$

Double power -> 3 dB

$$\log(2A) = \log(A) + \log(2) = \log(A) + 0.3 \longrightarrow 10\log_{10}(2A) = 10\log_{10}(A) + 3$$

e.g. speed dependence

$$\log(A^n) = n\log(A) \longrightarrow 10\log_{10}(A^n) = 10n\log_{10}(A)$$

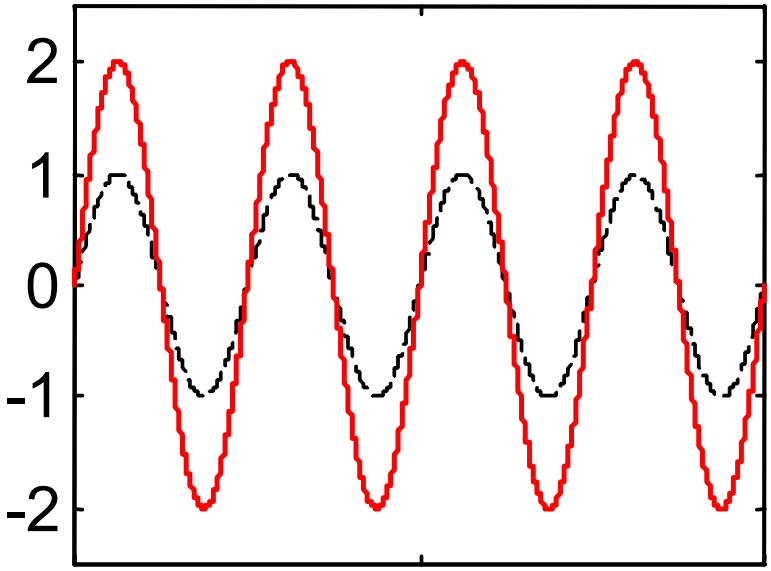
$$\log(A + B) = \ldots \longrightarrow 10\log_{10}(A + B) = \ldots$$

'dB addition'

ADDING DECIBELS – COHERENT SOURCES

- ‘Coherent’ sources are directly related. The combined sound pressure level depends on the relative phase.
- Examples: components at engine firing frequency and its harmonics from the engine, intake and exhaust are coherent.
- e.g. two single frequency sources with same magnitude:

two sources **in phase**: $|p| = p_1 + p_2$ **$L_p = L_1 + 6$ dB**



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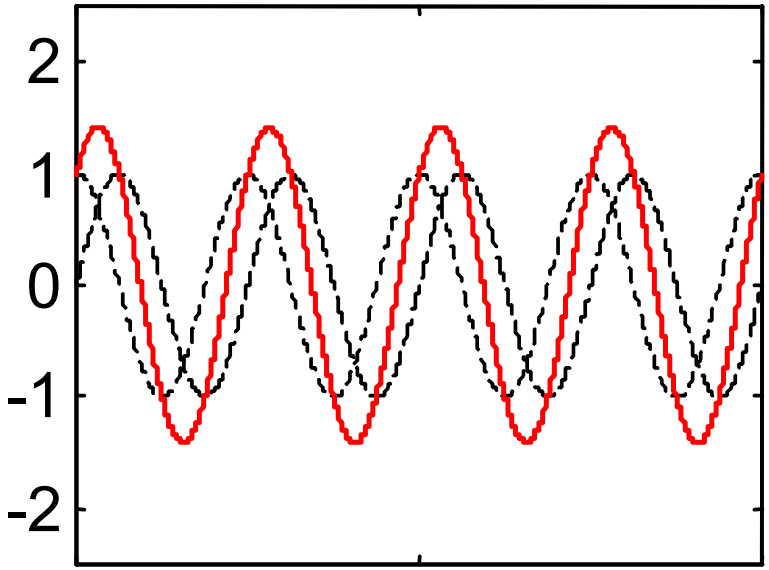
- Examples: components at engine firing frequency and its harmonics from the engine, intake and exhaust are coherent.
- e.g. two single frequency sources with same magnitude:

two sources **90^0 out of phase**:

$$L_p = L_1 + 3 \text{ dB}$$

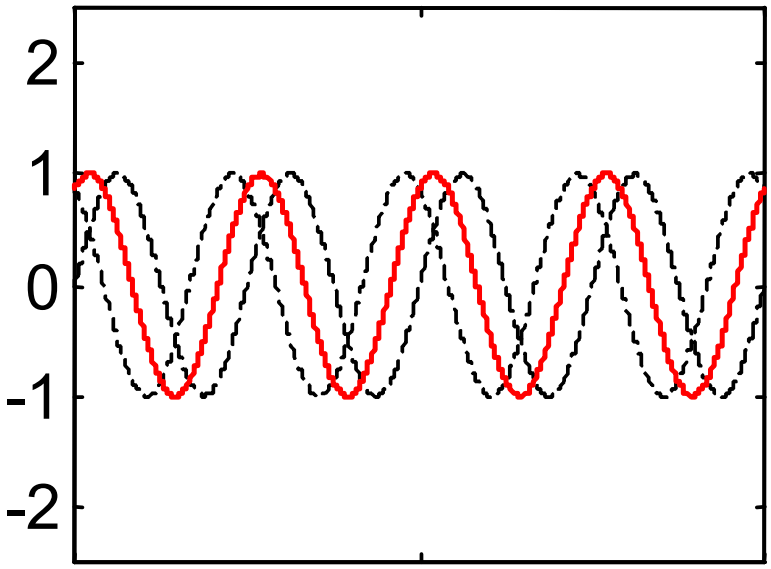


ADDING DECIBELS – COHERENT SOURCES

- ‘Coherent’ sources are directly related. The combined sound pressure level depends on the relative phase.
- Examples: components at engine firing frequency and its harmonics from the engine, intake and exhaust are coherent.
- e.g. two single frequency sources with same magnitude:

two sources **120^0 out of phase**:

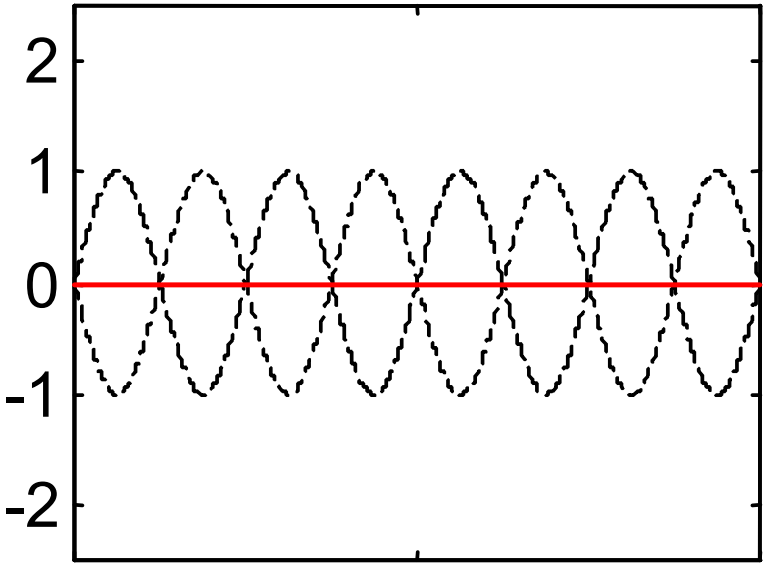
$$L_p = L_1 + 0 \text{ dB}$$



ADDING DECIBELS – COHERENT SOURCES

- ‘Coherent’ sources are directly related. The combined sound pressure level depends on the relative phase.
- Examples: components at engine firing frequency and its harmonics from the engine, intake and exhaust are coherent.
- e.g. two single frequency sources with same magnitude:

two sources **180^0 out of phase**: $|p| = p_1 - p_2$ **$L_p = \quad -\infty$ dB**



ADDING DECIBELS – INCOHERENT SOURCES

- ‘Incoherent’ sources are unrelated.
- e.g. sound at different frequencies, independent random signals
- In this case we add their **mean-square pressures**.

$$\overline{p^2} = \overline{p_1^2} + \overline{p_2^2}$$

- Or in decibels:

$$L_\Sigma = 10\log_{10}\left(10^{L_1/10} + 10^{L_2/10} + \ldots\right)$$

ADDING DECEIBELS - EXAMPLE

- Suppose we have two sources that by themselves produce sound pressure levels of **68** and **72** dB. What is the combined sound pressure level?

  (a) 140 dB?

  (b) 70 dB?

  (c) 73.5 dB?

  (d) 76.2 dB?

$$L_\Sigma = 10\log_{10}\left(10^{L_1/10} + 10^{L_2/10} + \ldots\right)$$

ADDING DECIBELS - SUMMARY

(1) *Almost all practical cases*

- sound in different frequency bands...
- sound from sources at different frequencies...
- sound from unrelated (uncorrelated) random sources...
- sound from correlated sources in terms of a band-average at high enough frequencies...

.... add the mean-*square* values

(2) *A few special cases*

- sound from the same source coming via different paths (e.g. reflections)...
- sound from sources which are directly related (correlated) i.e. come from the same process (e.g. engine firing frequency)...

.... add the pressures accounting for phase

Noise Pollution

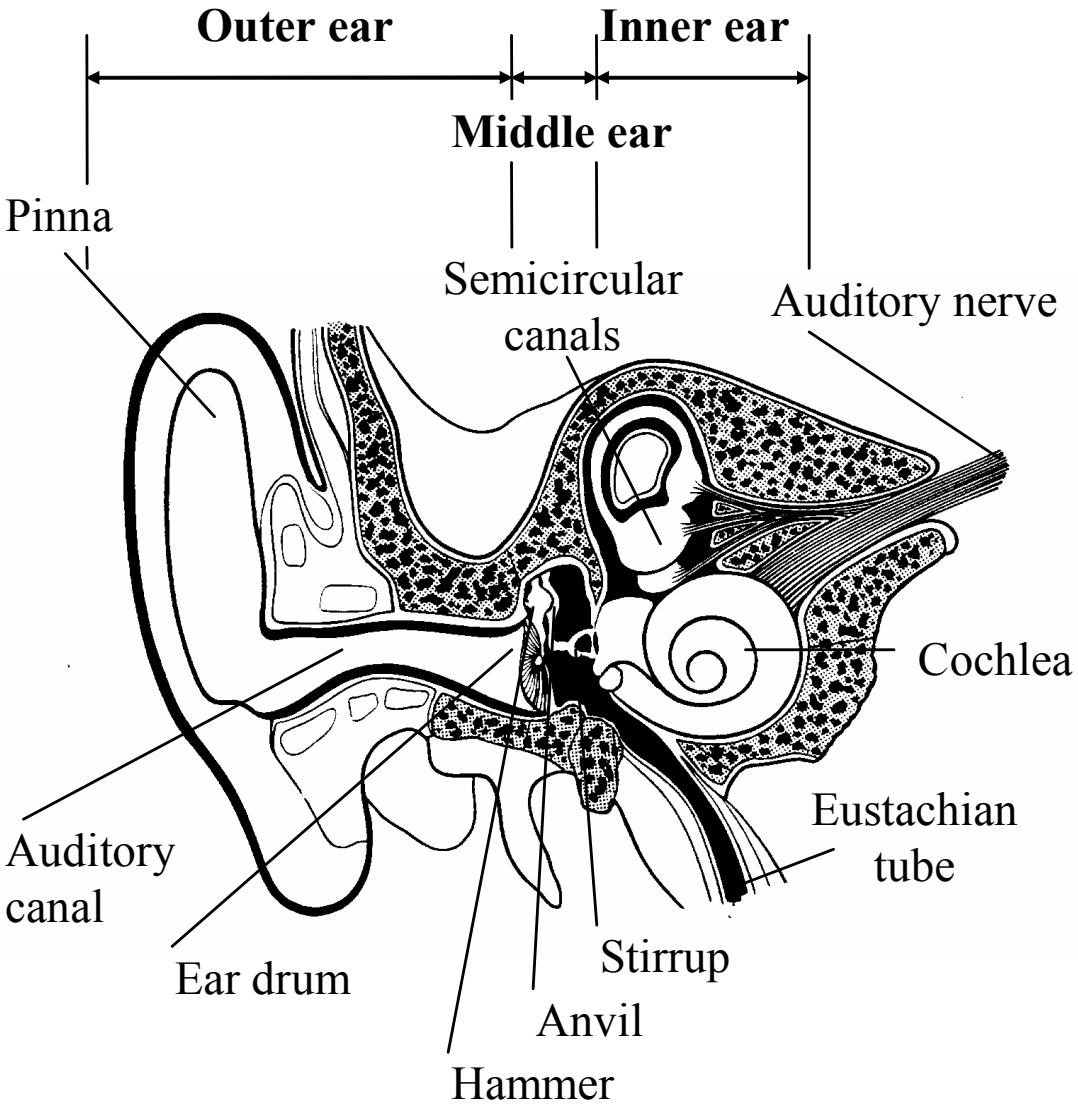
The physical and psychological problems caused by exposure to excessive noise levels are more serious in poor developing countries than in the developed ones.

This is related to many factors including the need for survival, leading to lack of attention to noise problems on the part of both workers and management.

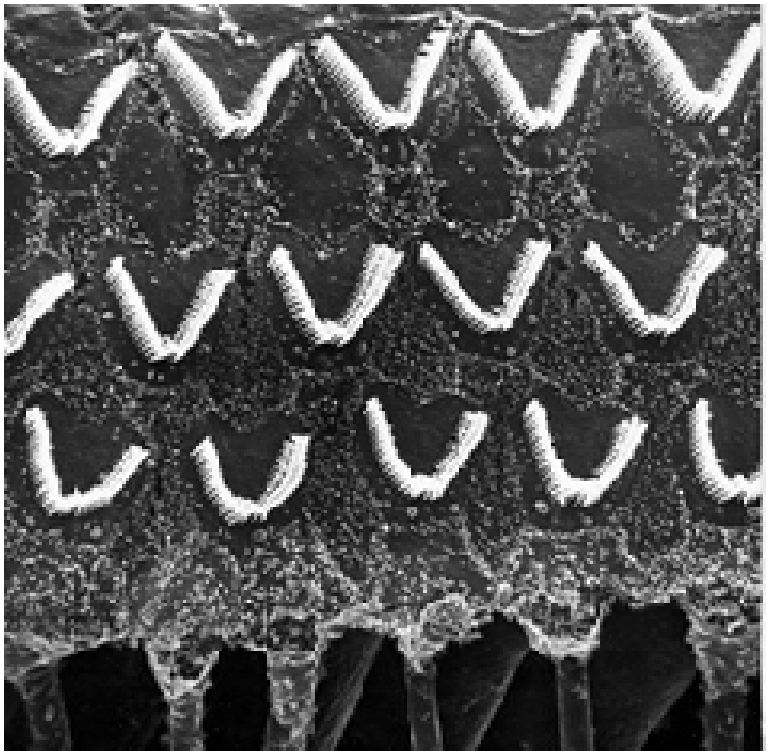
Thus, more studies should be directed to this issue to increase the environmental awareness and human safety.

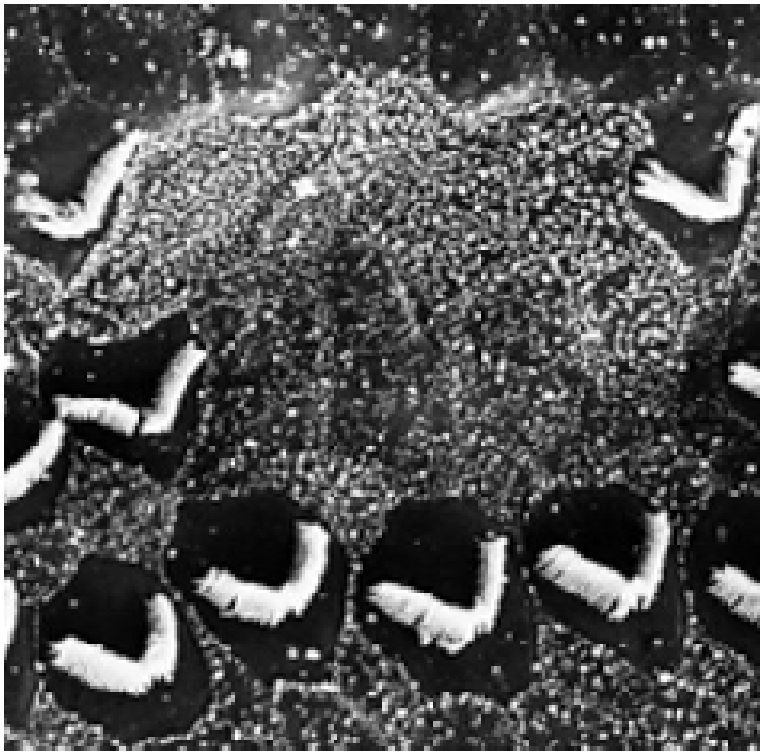
Harms of Noisy Environment

1. Damage hearing
2. Impair safety
3. Hinder communication
4. Cause hypertension, fatigue and loss of concentration
5. Be annoying.
6. Be a measure of lack of civilization.

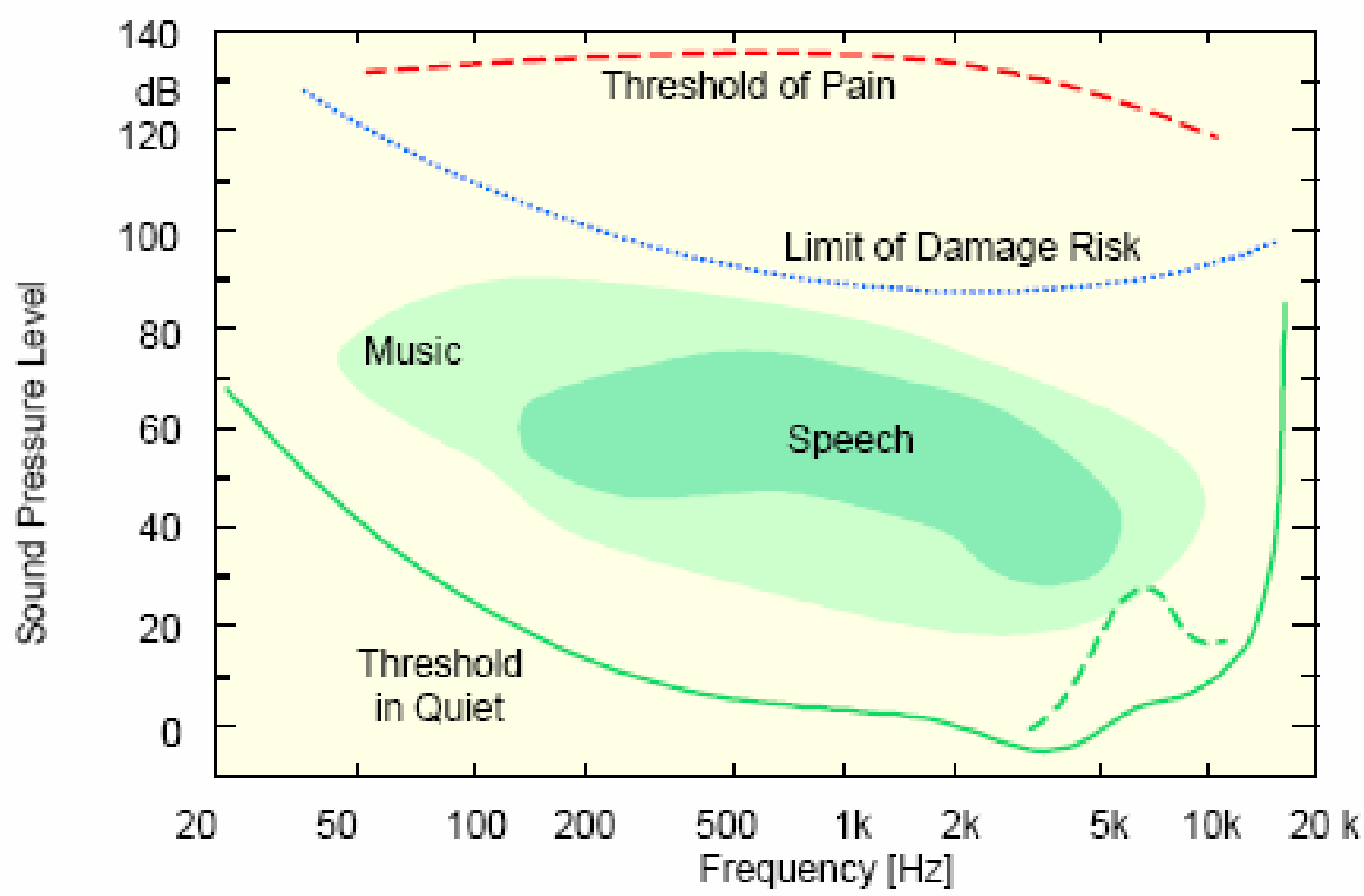

Outer ear
Inner ear
Middle ear
Pinna
Semicircular canals
Auditory nerve
Cochlea
Eustachian tube
Auditory canal
Ear drum
Stirrup
Anvil
Hammer

Hair Cells on the Cochlea

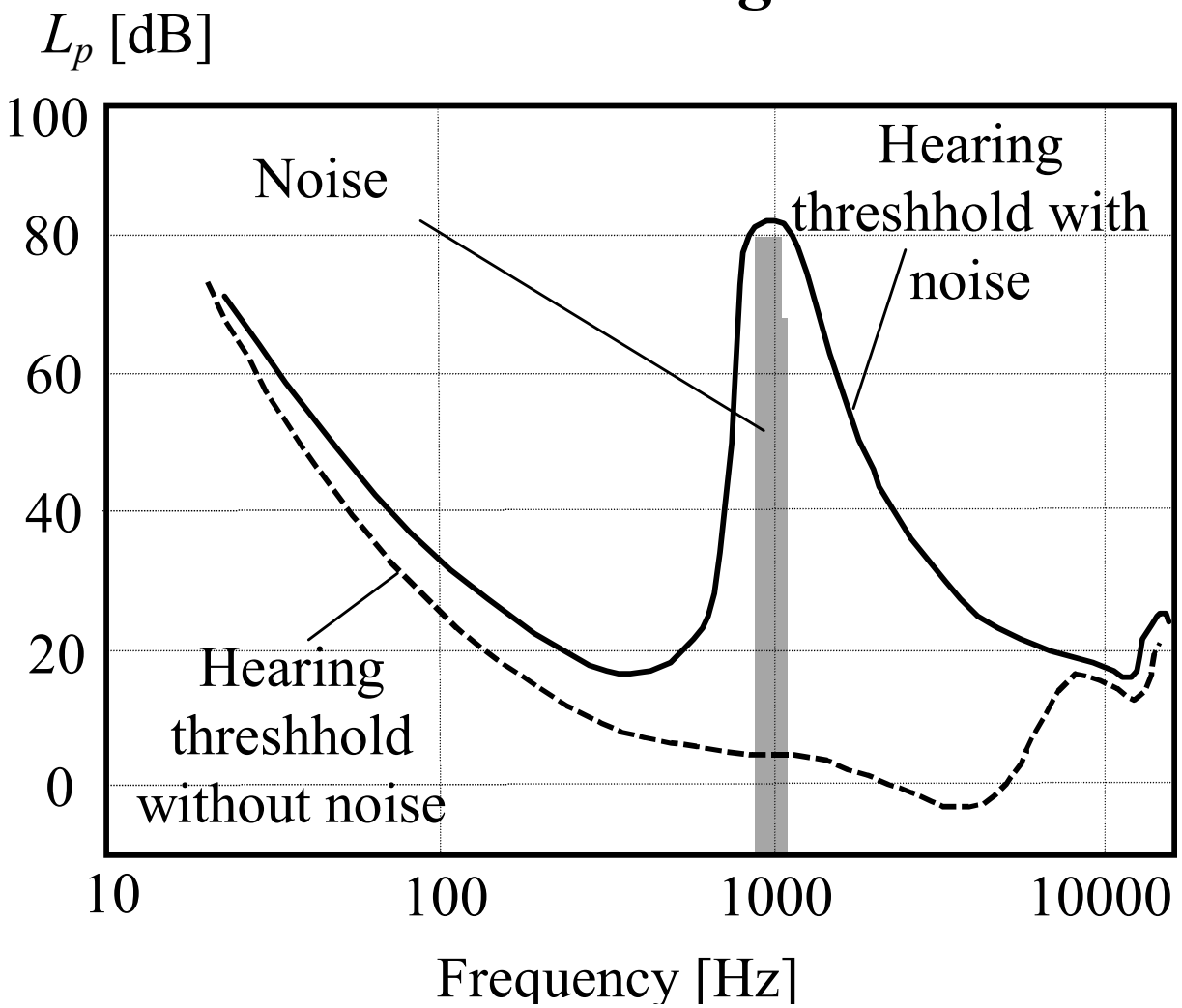


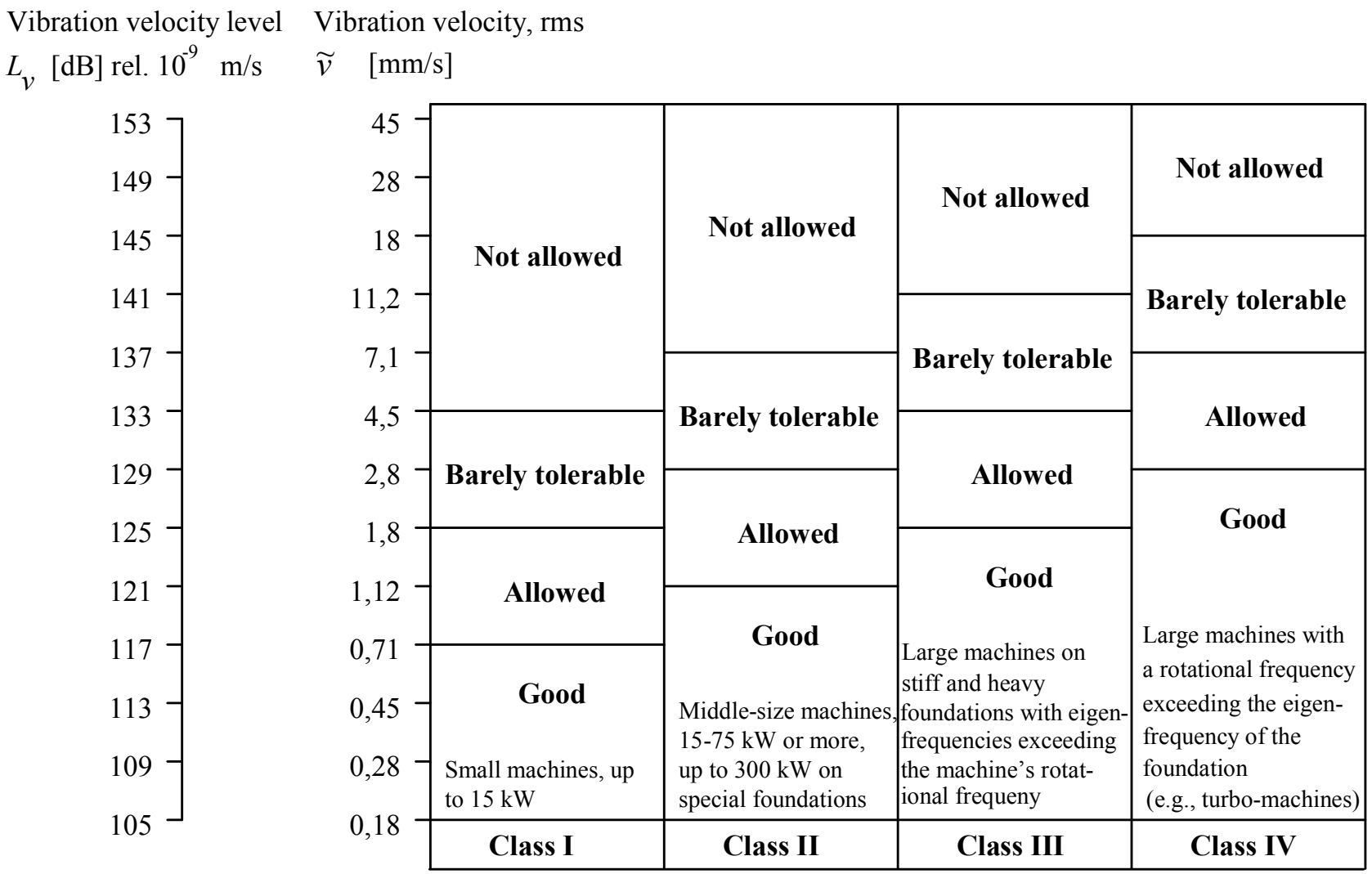


Auditory Field



Masking


L_p [dB]
100
80
60
40
20
0
Noise
Hearing threshhold with noise
Hearing threshhold without noise
10
100
1000
10000
Frequency [Hz]


Vibration velocity level L_v [dB] rel. 10^{-9} m/s
Vibration velocity, rms $\tilde{v}$ [mm/s]
153
149
145
141
137
133
129
125
121
117
113
109
105
45
28
18
11,2
7,1
4,5
2,8
1,8
1,12
0,71
0,45
0,28
0,18
Not allowed
Barely tolerable
Allowed
Good
Small machines, up to 15 kW
Class I
Not allowed
Barely tolerable
Allowed
Good
Middle-size machines, 15-75 kW or more, up to 300 kW on special foundations
Class II
Not allowed
Barely tolerable
Allowed
Good
Large machines on stiff and heavy foundations with eigen-frequencies exceeding the machine's rotat-ional frequeny
Class III
Not allowed
Barely tolerable
Allowed
Good
Large machines with a rotational frequency exceeding the eigen-frequency of the foundation (e.g., turbo-machines)
Class IV

Effect of Vibration on Man